High-Frequency Acoustic Propagation in Shallow, Energetic, Highly-Salt-Stratified Environments

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LONG-TERM GOALS

The long term goal of this research is to measure and understand high-frequency, line-of-sight acoustic propagation in an estuarine environment characterized by strong tidal flow, often large salinity stratification, high shear, high dissipation rates of turbulent kinetic energy, and increased water property variability.

OBJECTIVES

Acoustic propagation techniques provide a means for remote-sensing of the path-averaged statistical structure and motion of the intervening flow, providing information on the 2-dimensional characteristics of turbulence, microstructure, and advection. Estuaries provide an excellent environment to quantify stratified turbulence and its influence on acoustic propagation, as these environments provide a broad range of stratification and turbulence intensities within a single tidal cycle. The primary objective is to conduct high-frequency, line-of-sight acoustic propagation measurements in Fall 2012 in the Connecticut River estuary, at the same location and time of year as previous direct measurements of turbulence parameters and broadband acoustic backscattering have been performed in 2008 and 2009 (funded through ONR Physical Oceanography). In addition, shipboard measurements of high-frequency broadband acoustic backscattering, currents (using a 1.2 MHz ADCP), and continuous CTD measurements will be performed in order to support the interpretation of the scintillation measurements. Secondary objectives include testing the validity of the existing theoretical framework for propagation of high-frequency sound through a turbulent medium, determining the range of conditions under which it is accurate, and quantifying the importance of anisotropy.

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APPROACH

Decades of research has shown that the propagation of sound waves through a moving random medium, such as the atmosphere [1] or the ocean [2], provides a means for remote-sensing of the path-averaged statistical structure and motion of the intervening fluid medium. These techniques, however, have been less exploited at high acoustic frequencies and over short ranges, applicable in shallow coastal waters, where there can be highly variable fluid flows, with intermittent strong mixing and high stratification, depending on the tidal cycle, wind, currents, and topography. Under these conditions, it is typical to encounter regimes of homogenous and isotropic turbulence, and for propagations distances over which the Rytov approximation holds, it is possible to infer path-averaged turbulence parameters using Tatarski's weak scattering theory. Though there have been a number of theoretical and numerical studies [e.g. 3, 4] that apply these techniques to investigating turbulence in shallow waters, and its influence on acoustic propagation, there have only been a handful of measurements performed [e.g. 5], with a focus on relatively unstratified conditions. The high-frequency, line-of-sight acoustic scintillation measurements that are the core of this project will be performed in the CT River, a highly-salt-stratified estuarine environment, in Fall 2012, and should provide the framework for a better understanding the complex problem of high-frequency sound propagation in shallow, highly-stratified, highly-energetic environments, and for setting bounds on the range of validity of Tatarski's weak scattering theory. Quantifying and understanding the influence of turbulence on high-frequency acoustic propagation, for example quantifying the times scales of variability, is particularly important in the context of recent developments in the area of high-frequency, shallow-water, acoustic communications, as well as being particularly relevant to the development of acoustic observatories. Acoustic observatories provide a powerful remote-sensing technique for real-time long-time-series monitoring of transport, mixing, and circulation patterns in coastal regions. Measurements of turbulence and microstructure in the ocean are usually performed with high-spatial resolution instruments, such as ADVs, shear probes, or fast-response thermistors. However, these are time-consuming, point measurements, which can be influenced by local inhomogeneities and may not be representative of the mean flow. In contrast, high-frequency acoustic propagation techniques average over local anomalies along the transmission path and can provide information not only on path-averaged dissipation rates of turbulent kinetic energy but also on mean flows.

The measurements involves the use of a reciprocal transmission acoustic scintillation system to extend existing high-frequency acoustic propagation techniques [5-8] to study the 2-dimensional (2-d) characteristics of advection, microstructure, turbulence, and turbulence anisotropy, in shallow estuarine environments characterized by strong tidal flow, high shear, stratification and dissipation, and increased water property variability. Of particular interest are 1) the effects of turbulence anisotropy on the effective refractive index fluctuations, as the refractive index fluctuations can be related to turbulence parameters, such as the dissipation rate of turbulent kinetic energy, under some conditions, 2) the presence and influence of more coherent 3-D wave structures generated in these highly sheared, high-Reynolds number environments (Figure 1).

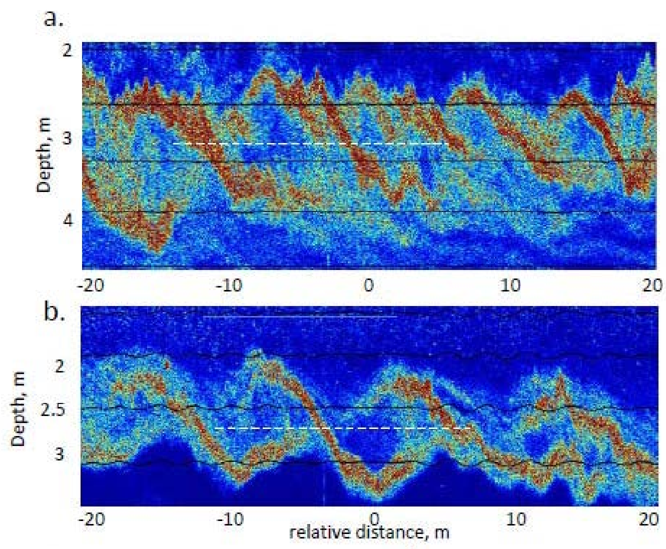

Figure 1. Examples of high-Reynolds number shear instabilities at two locations in the CT River in November 2009 imaged using broadband acoustic backscattering.

The measurements will be conducted with an already operational (with some testing and maintenance required), cabled, acoustics propagation system with real-time data-collection capabilities (Figure 2). The system consists of two, 120-kHz, 4-transducer, 1m^2 square acoustic arrays mounted on tripods 3 m above the bottom. One tripod is the master, and contains all the electronics, including timing and signal digitization. The tripods will be separated by approximately 100 meters, depending on a number of parameters relating to the deployment site. The novel and key capability of this system is that every transducer has both transmitting and receiving capabilities, allowing forward and reciprocal acoustic transmissions along 16 different paths.

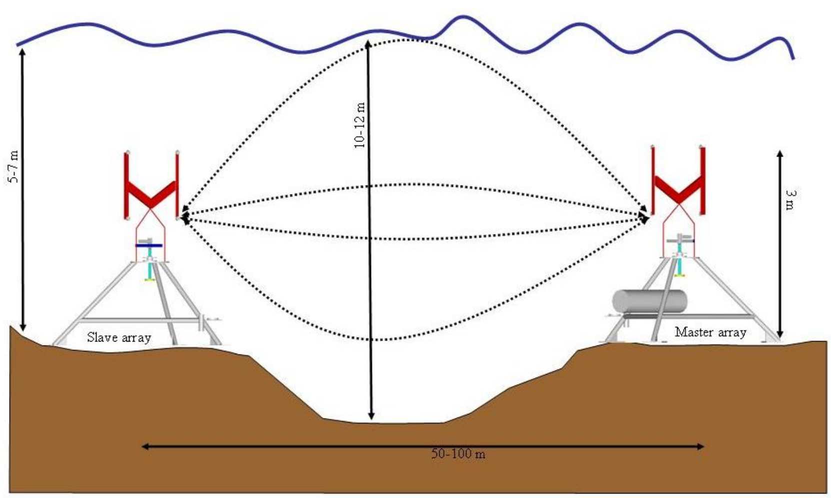

Figure 2. The high-frequency acoustic propagation system as it will be deployed in the CT River in Fall 2012. The dominant flow is in/out of the page relative to this configuration.

The measurements will combine acoustic scintillation, two-dimensional angle of arrival fluctuations, and reciprocal transmission techniques:

Acoustic scintillation: Acoustic scintillation refers to the accumulation of the effects of the continuously evolving amplitude and phase of the acoustic waves as they propagate through a fluctuating medium. Mean fluid motion [5], turbulent velocity fluctuations [6], and temperature and salinity fluctuations [8] contribute to the forward scattering of high-frequency acoustic waves and thus to the variability in the effective refractive index of the fluid. Measurements of acoustic scintillation, in combination with an understanding of the theoretical framework of acoustic propagation through a turbulent medium, can be used to infer path-averaged parameters of intervening turbulence. In addition, measurements of acoustic scintillation allow the mean current flow perpendicular (cross-path) to the acoustic propagation path to be determined by exploiting the coherence of fine-structure advected across two closely spaced horizontal transducers [5].

2-dimensional angle of arrival: Using the tomographic array of acoustic transducers, properties of the 2-dimensional arrival angle can be related to the properties of the 2-d turbulent flow, allowing turbulence anisotropy to be investigated [7]. The scatter in the angle of arrival fluctuations is related to the intensity of the refractive index fluctuations, which are related to the path-averaged turbulent kinetic energy, if velocity fluctuations dominate over, or can be separated from, temperature and salinity fluctuations using reciprocal transmission techniques.

Reciprocal transmission: Reciprocal transmission can be used to separate the effects of ocean currents on acoustic propagation from the effects of sound speed structure, and to separate the contribution to scattering from velocity fluctuations and temperature and salinity fluctuations. The high-frequency acoustic propagation array will be used to obtain measurement of the following path-averaged properties of the flow:

1) the component of horizontal flow resolved along the acoustical path (though this is expected to be small in this particular experiment due to the experimental set-up), derived from reciprocal transmission,
2) the horizontal component of flow perpendicular to the acoustic path, derived from acoustical scintillation drift,
3) the vertical shear, derived from (1) and (2) for vertically separated depths,
4) the mean density at the depth of each acoustical path, using the two-way travel time to get sound speed, together with an independent measure of the T-S relationship,
5) the bulk Richardson number, from (2) and (4),
6) the dissipation rate of turbulent kinetic energy at each depth, using reciprocal transmission analysis, and
7) the degree of turbulence anisotropy, using 2-dimensional angle of arrival techniques, and again using reciprocal transmission to separate the contribution of vector and scalar components. Turbulence anisotropy is expected to be most pronounced when the there is significant mean vertical shear.

The proposed site for the measurements is the Connecticut River. The field measurements will be performed for one week, encompassing many tidal cycles, with different degrees of turbulence intensities generated throughout any given tidal cycle, in Fall 2012. The choice of the CT River is motivated partly by the physics of the flow satisfying the above criteria (highly stratified and energetic), as well as by the potential for capitalizing on the research already conducted at this location (measurements funded by ONR Physical Oceanography in 2008 and 2009). These previous field measurements were focused on measuring and understanding high-frequency broadband acoustic backscattering in highly-stratified, energetic estuarine environments together with direct microstructure measurements [9]. The measurements already performed at this field site provide significant insight into the expected flow regimes.

WORK COMPLETED

Work has commenced on testing and upgrading the scintillation system. The transducers will be upgraded to improve signal to noise ratios, and longer cables will be added to provide additional flexibility at the deployment site.

A one-day reconnaissance trip to the CT River was undertaken in June 2011 to assess the best location for deployment of the scintillation system, balancing both the scientific needs and logistical difficulties. A site south of the I-95 and railroad bridges has been identified.

The revised schedule and milestones for this experiment are as follows:

- Spring 2011: Modeling of acoustic propagation paths based on the CTD data collected in the CT River in 2009.
- Summer 2012: Scintillation system transported to WHOI and its operation tested. Any maintenance needs addressed. Preparations for Fall deployment underway.
- Fall 2012: Field deployment in the CT River.
- Winter 2012: Analysis and interpretation of scintillation data. Publication of results in peer-reviewed journals.

RESULTS

There are no new results at this point in time as the field measurements have not yet been performed.

IMPACT/APPLICATIONS

Increased understanding of high-frequency acoustic propagation in shallow estuarine environments characterized by strong tidal flow, high shear, strong stratification and dissipation, and increased water property variability. Assessment of the importance of anisotropy and 3-D structure of turbulence in determining acoustic propagation in these environments.

RELATED PROJECTS

Lavery, A.C. and Geyer, W.R. "Analysis of the Transition to Turbulence in Highly-Stratified and Energetic Shear Flows Using Broadband Acoustic Backscattering" ONR Physical Oceanography (Grant number N00014-11-10281).

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